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AN ASSESSMENT OF SOURCE CONTRIBUTIONS TO THE OZONE CONCENTRATIONS IN SOUTHERN ONTARIO 1979 - 1985

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E. PICHÉ, Director
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by

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TABLE OF CONTENTS

	Page
Abstract	1
1. Introduction	2
2. Data Availability and Methodology	4
3. O_3 Episode Analysis	6
4. Source Contributions	10
5. Summary and Conclusions	12
References	13
Acknowledgements	15
Tables	16
Figures	18

ABSTRACT

Source contributions to the surface O_3 concentrations in southern Ontario were assessed for the 1979-1985 period. Ozone episode analyses indicate a frequency of about nine episodes per year (15 episode-days). These occur primarily in the summer months and are generally manifestations of the northern extent of the O_3 problem in eastern North America. Widespread elevated O_3 levels tend to occur under weather classes indicative of back or centre of the high pressure situations and associated flow/trajectory from areas S/SW of the lower Great Lakes. These episodes vary considerably from year-to-year. Local impacts on O_3 levels are generally small.

A study of O_3 levels during cloud-free summer days for the period 1981-1985 gave local "background" O_3 levels of about 20 to 30 ppb daily and 30 to 50 ppb hourly maxima. The O_3 contributions from the U.S. to southern Canada (assuming local "background" O_3 levels to be independent of wind direction) were estimated to be 30 to 35 ppb daily and 30 to 50 ppb hourly maxima. These results indicate an overall O_3 contribution of about 50 to 60% from the U.S. to southern Ontario. For episode days, the U.S. contribution is even more significant.

1. INTRODUCTION

Elevated surface ozone concentrations in southern Ontario have been of concern to the agricultural communities since the early 1960's when O_3 was shown to be a cause of tobacco injury (Mukammal, 1965). At present, there is a network of over 30 O_3 monitoring sites in southern Ontario to investigate the potential of long-range transport of O_3 into Ontario, and to provide information to assess the damage of O_3 to crops such as white beans. Results from this network for the past decade have revealed that the Ontario's air quality criterion for O_3 (80 ppb hourly average) is frequently exceeded during the growing season (especially June, July and August). Moreover, it has recently been estimated that if control efforts could be developed to avoid O_3 excursions above the criterion, Ontario farmers would benefit by up to $23 million per year [typically $15 million per year (1980 dollars)] in extra production of various agricultural crops (Linzon et al., 1984). It is thus economically important to determine the relative contributions of inflow O_3 and local production to the total O_3 observed in southern Ontario. This is required especially on elevated O_3 days, so that appropriate and effective abatement strategies can be developed and implemented.

O_3 concentration at any given location is the combined result of O_3 originating from a number of different sources. These sources include:

(i) "background" troposphere;
(ii) generation from local anthropogenic emissions (precursors);
(iii) long range transport and accumulation in high-pressure weather systems;
(iv) formation in urban plumes downwind of cities;
(v) injection from the stratosphere into the troposphere and subsequent transport to the surface.

The meteorological conditions associated with O_3 levels in southern Ontario have been examined in numerous studies (e.g. Chung, 1977; Yap and Chung, 1977; Mukammal et al., 1982 and 1985; Heidorn and Yap, 1986). These studies show that O_3 episodes in southern Ontario typically occur on the rear sides of anti-cyclones, or in the warm sectors of cyclones during the summer months (Figure 1). These researchers have strongly implicated long range transport of O_3 as the significant or main contributor to the observed high O_3 levels. There is, nevertheless, evidence of O_3 formation from local emissions in southern Ontario, especially downwind of Metropolitan Toronto and the Sarnia industrial area (e.g. Lusis et al., 1976 and 1985; Chung, 1977; Yap and Chung, 1977; Shenfeld et al., 1978). Under appropriate conditions, these local/urban areas and associated precursor emissions can contribute measurably (up to about 20-40 ppb) to the downwind O_3 burden, and thus at times play an important role in causing hourly O_3 concentrations to exceed the provincial air quality criterion of 80 ppb. Recent studies by Mukammal et al. (1985) have also suggested that tropospheric and stratospheric contributions may, at times, be a major source to the total observed surface O_3 concentrations in Ontario.

The assessment of source contributions to the observed O_3 concentrations in southern Ontario is thus needed to develop effective control strategies. Based on meteorological analyses of the O_3 data for the period 1979-1985, we have tried to characterize the O_3 problem in southern Ontario. We have attempted to quantify the "background" tropospheric O_3 in southern Ontario, the inflow of O_3 from U.S. to southern Ontario (i.e. the long range transport contribution) and the local urban downwind O_3 contribution.

2. DATA AVAILABILITY AND METHODOLOGY

Source contributions to the surface O_3 concentrations in southern Ontario were investigated for the period 1979-1985 during the months May to September. Figure 2 shows the O_3 monitoring sites, which consist of over 30 chemiluminescent instruments in urban and rural areas of southern Ontario. In addition, O_3 data from three sites in Michigan (Figure 2) were available for the period 1981 to 1984. Data from all these sites were used initially to analyse O_3 episodes and their relationship to meteorological conditions. "Episode days" were defined as days on which widespread elevated O_3 levels over 80 ppb (maximum hourly concentration) occurred simultaneously at more than eight monitoring sites. "Episodes" were defined as distinct events associated with episode days. The associated meteorological analyses consisted of air parcel trajectory and synoptic weather schemes (as described in Heidorn and Yap, 1986; Yap and Kurtz, 1986). Basically, the synoptic weather pattern for each day in the 1979-1985 period (May to September) was subjectively classified into eight distinct weather regimes by examination of the 0700 EST surface weather map for the day in question. The eight classes are: Class 1: Post-cold front/pre-high pressure ridge. Class 2: High pressure ridge. Class 3: Post-ridge/pre-warm front. Class 4: Warm front. Class 5: Cyclonic. Class 6: Cold front. Class 7: Stationary front. Class 8: weak pressure gradient. The weather characteristics of episode days also were investigated. To study the flow characteristics associated with episode days, two-day surface geostrophic back trajectories of air parcels were determined for O_3 episode days in southern Ontario. The trajectories were calculated with a 3-h time step for air parcels arriving at London, Ontario at 0700 EST on the day in question.

Data from Sarnia, Simcoe, Long Point and St. Catharines were evaluated to quantify the amount of O_3 entering southern Ontario from the U.S. (above the local "background" levels). These four sites were analysed for the summer months (June, July and August) for the period 1981 to 1985. Local "background" levels at the above sites were determined from a meteorological data screening by considering only days that were relatively cloud-free with windflow and back trajectories from the north within the Ontario sector. To determine the O_3 associated with flows from the south, a similar screening was applied to consider only those days with trajectories from the U.S. sector. The O_3 level from the south minus that from the north was then attributed to the U.S. contribution to southern Ontario under cloud-free conditions (i.e. the O_3 entering the Province). This assumes that local "background" O_3 levels are independent of wind direction.

The effect of O_3 scavenging in urban centres and the formation of O_3 in urban plumes downwind of cities were also investigated. Urban and adjacent rural data for metropolitan Toronto and Sarnia were used.

3. O_3 EPISODE ANALYSIS

"Episode days" in southern Ontario for the period 1979 to 1985 inclusive are shown in Table 1. These occurred on average 15 times per year with a maximum of 25 such days in 1983 and a minimum of 7 in 1982. Although O_3 episode days were confined to the months May to September, most of the occurrences (92% of the occasions) took place in the summer months (June, July and August). In terms of episodes (i.e. distinct events associated with episode days), there were on average 9 per year. Episodes varied from a maximum of 13 in 1983 to a minimum of 5 in 1979 and 1982, and 89% of these occurred in the summer months (Table 1). The duration of episodes was also quite variable, ranging from one day to eight days (Figure 3). Nevertheless, most of the episodes were of 1 to 2 days duration (87%). Of the 61 episodes identified during the period 1979-1985, only one lasted more than four days. This occurred in 1983. The frequency of O_3 episode days/episodes thus varies considerably from year to year and can be largely ascribed to the fluctuations in the synoptic weather patterns especially in the vicinity of the Great Lakes regions.

The relationship between episode day and the synoptic weather pattern over southern Ontario was next analysed. The results (Table 2 and Figure 4) indicate that episode days were mainly associated (73% of the occasions) with three distinct weather regimes, namely, post ridge/pre-warm front situations (33%), high pressure ridge situations (24%) and weak pressure gradients (15%). Statistics for this study period indicate that these three weather classes occurred 55% of the times during the months May to September (20% with the post ridge/pre-warm front, 22% with the high pressure ridge and 13% with weak pressure gradients). This synoptic climatology of episode days thus indicates that widespread elevated O_3 levels tend to

occur under weather classes generally indicative of back or centre of the high pressure situations. There is also a somewhat greater probability of occurrence of episode days during the post ridge/pre-warm front situations. For southern Ontario, this would suggest an associated flow from areas generally S/SW of the lower Great Lakes. Such a pattern is similar to the findings of Kelly et al. (1986) for areas of southeastern Michigan.

An examination of the flow characteristics and directional dependence associated with O_3 episode days using two-day back trajectories of air parcels confirms the previous inference. Indeed, trajectories generally reach southern Ontario from the S/SW paths over heavily industrialized and urban areas of the U.S., which are potential source regions of O_3 and its precursors (Figure 5). In addition, episodic conditions in southern Ontario for the period 1979 to 1985 invariably occurred with flows from the U.S. (more than 95% of the cases during the seven year period). The influence of the U.S. on O_3 levels in southern Ontario can also be inferred from the O_3 data in Michigan. An analysis of the data from the three sites in Michigan for the period 1981 to 1984 indicated that for 90% of the O_3 episode days in Ontario there were concurrently elevated O_3 levels (daily maximum >80 ppb) in Michigan. Thus, widespread occurrences of elevated O_3 levels in southern Ontario are often not unique to Ontario at any given time, but rather are likely to be manifestations of the northern extent of the O_3 problem in eastern North America. It is suggested that episode days in Ontario are often linked to the regular flow of O_3 and its precursors from areas S/SW of the Great Lakes in the form of an "ozone river". An "ozone river" is a term used when O_3 flows above the surface layer, and is able to traverse great distances in substantial concentrations without extensive nocturnal consumption by NO_x. This phenomenon was proposed by Wolff and Lioy (1980). The fact that episodes usually last 1 to 2 days over southern Ontario would also support the hypothesis that southern Ontario is

typically on the northern edge of the O_3 problem in eastern North America. Previous studies of O_3 episodes in eastern America show many cases where the elevated surface O_3 levels occurred only south of the lower Great Lakes. It is thus apparent that synoptic conditions (especially the track (movement and speed) of anticyclones across the area), will often determine the duration of an episode, and whether an episode will occur over southern Ontario. It should be noted, however, that O_3 episodes in excess of four days over southern Ontario are very rare (Figure 3). O_3 episodic analyses suggest that the control of O_3 precursor levels on a local or regional scale in southern Ontario, during episode days, may not be effective in preventing excursions (i.e. O_3 > 80 ppb), since the background O_3 entering the Province may often be very significant.

It has been established that high concentrations of O_3 can be generated and transported downwind of moderate to large cities (Wolff et al., 1977; Spicer et al., 1982; Kelly et al., 1986). For southern Ontario, such an effect has been noted for areas to the east and northeast of metropolitan Toronto, and to the east of Sarnia. In the present study, the local impacts on "episode days" were investigated. Figure 6 depicts the spatial pattern of the average hourly O_3 maxima for the 103 episode days during 1979 to 1985. In this figure there is a depression of O_3 levels in the urbanized Toronto-Hamilton area which can be attributed to local scavenging by nitric oxide. There is some suggestion of elevated O_3 levels downwind of the Detroit-Windsor-Sarnia area, but a similar effect downwind (i.e. NE) of the Toronto-Hamilton corridor is not evident. Data which the Ontario Ministry of the Environment collected prior to 1980 had suggested areas of noticeable impact to the east and northeast of metropolitan Toronto and to the east of Sarnia. For example, the downwind urban effect of Toronto was often detected at Stouffville (a rural site NE of Toronto).

Stouffville O_3 concentrations prior to 1980 were generally higher than that of Toronto, and excursions above 80 ppb were more frequent there than in Toronto, (Figures 7 and 8). The preliminary investigation of forward trajectories from metropolitan Toronto on episode days tends to suggest that there may have been a slight easterly shift in airflow occurrences during the 1980's. Hence, the downwind impact on Stouffville would be reduced. Although there are no data from nearby rural sites to the east of Toronto, data from the intermediate site at Oshawa would tend to support this hypothesis. Figure 8 shows that excursions are more frequent at Oshawa than Stouffville during the 1980's. It is nevertheless evident that in southern Ontario, local impacts on O_3 levels are generally small, and therefore, local control measures will be relatively ineffective in lowering exceedances of the air quality criterion for O_3.

4. SOURCE CONTRIBUTIONS

The surface O_3 concentration at any given location is the combined result of O_3 originating from a number of different sources. In this study an attempt was made to quantify the amount of O_3 entering southern Ontario from the U.S. by analysing the data from four sites located near the US-Ontario border. The data were subjected to a meteorological stratification to consider only cloud- free days, with high insolation during the summer months of 1981- 1985. The local "background" ozone was derived by considering only those days which met the above criteria and had associated airflows in the Ontario sector (i.e. typically from the north). The background O_3 levels and associated diurnal characteristics are shown in Figure 9. These results indicate a daily average local "background" level of 22 ppb for Sarnia, 30 ppb for Simcoe, 33 ppb for Long Point, and 20 ppb for St. Catharines. The diurnal "background" levels showed average hourly maxima of 33 for Sarnia, 44 for Simcoe, 49 for Long Point and 35 for St. Catharines. The slightly lower values for Sarnia and St. Catharines probably reflect the more urbanized nature of these sites and the possible occurrences of local scavenging. Contributions from the U.S. to southern Ontario were then determined by considering only those selected days on which the flow was from the U.S. sector. The O_3 levels and associated diurnal characteristics for flows from the U.S. are shown in Figure 10. The differences between these levels and the "background" were then attributed to the U.S. contribution to southern Ontario under cloud-free conditions (i.e. the O_3 entering the Province). Here the assumption is made that local "background" O_3 levels are independent of wind direction. Contributions from the U.S. above background were quite significant with daily means of 29 ppb estimated at Sarnia, 32 ppb at Simcoe, 35 ppb at Long Point and 33 ppb at St. Catharines. The corresponding contribution to the hourly O_3 maxima ranged from 49 ppb at Sarnia, 42 ppb at Simcoe, 41 ppb at Long Point and 33 ppb at St. Catharines (Figure 11). These results indicate an overall contribution of O_3 from U.S.

to southern Ontario of about 50-60% in the summer months during cloud-free days. Thus, the O_3 attributed to long-range transport from the U.S. is a significant component to the levels observed in southern Ontario. This assessment of source contribution from the U.S. was not confined to episodic days only. Under such conditions, it is expected that the long range transport component from the U.S. would be even greater.

5. SUMMARY AND CONCLUSIONS

Assessment of source contributions to the surface O_3 concentrations in southern Ontario for the period 1979 to 1985 has shown that:

(1) O_3 episode days/episodes occured primarily in the summer months in southern Ontario and were generally manifestations of the northern extent of the O_3 problem in eastern North America. The synoptic climatology of episode days indicated that widespread O_3 levels tend to occur under weather classes indicative of back or centre of the high pressure situations, and thus with an associated flow and trajectory from areas generally S/SW of the lower Great Lakes. The frequency of episode days/episodes varied considerably from year-to-year and was largely governed by the synoptic weather pattern.

(2) Local impacts on O_3 levels, were generally observed downwind of the Detroit-Windsor-Sarnia area and metropolitan Toronto. These local impacts on O_3 levels, however, were generally small.

(3) Local "background" ozone in southern Ontario was estimated to be about 20 to 30 ppb daily and 30 to 50 ppb hourly maxima. These results indicated an overall contribution of O_3 from the U.S. to southern Ontario of about 50-60% in the summer months during cloud-free days (assuming local "background" O_3 levels to be independent of wind direction). On high O_3 days, the contributions from the U.S. were expected to be even more significant.

(5) Control of O_3 precursor levels on a local or regional scale in southern Ontario may not be effective in preventing excursions (i.e. O_3 > 80 ppb) since the background O_3 levels entering the Province are often very significant.

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Table 1

No. of "Episode Days" in Southern Ontario

Year	May	Jun	Jul	Aug	Sep	Total
1979	0	4	8	1	1	14
1980	1	5	5	2	0	13
1981	3	3	8	4	0	18
1982	0	1	3	3	0	7
1983	0	12	6	4	3	25
1984	0	5	8	4	0	17
1985	1	1	3	2	2	9
Total:	5	31	41	20	6	103

No. of "Episodes" in Southern Ontario

Year	May	Jun	Jul	Aug	Sep	Total
1979	0	1	2	1	1	5
1980	1	2	4	1	0	8
1981	1	3	5	3	0	12
1982	0	1	2	2	0	5
1983	0	3	5	3	2	13
1984	0	3	4	3	0	10
1985	1	1	3	2	1	8
Total:	3	14	25	15	4	61

Table 2

(a) Weather Class Stratification For "Episode Days" In Southern Ontario

Year	WEATHER CLASS 1	2	3	4	5	6	7	8	Total
1979	1	1	5	1	0	1	0	5	14
1980	0	3	4	1	1	2	0	2	13
1981	0	9	4	2	1	0	0	2	18
1982	1	2	3	0	0	0	0	1	7
1983	2	6	6	3	0	4	2	2	25
1984	1	2	9	0	0	2	0	3	17
1985	0	5	0	0	3	1	0	0	9
Total:	5	28	31	7	5	10	2	15	103
%	5	27	30	7	5	10	2	15	

(b) No. Of Days In Given Weather Class For Southern Ontario (Based On The Daily 1200Z Surface Weather Map, May. - Sept.)

Year	WEATHER CLASS 1	2	3	4	5	6	7	8	Total
1979	23	27	27	6	24	12	5	27	151
1980	21	38	20	7	24	26	6	11	153
1981	25	31	35	2	16	12	9	20	150
1982	19	37	38	5	10	9	8	26	152
1983	20	41	36	3	12	8	13	20	153
1984	37	26	35	4	13	16	4	18	153
1985	21	38	20	7	24	26	6	11	153
Total:	166	238	211	34	123	109	51	133	1065
%	16	22	20	3	12	10	5	13	

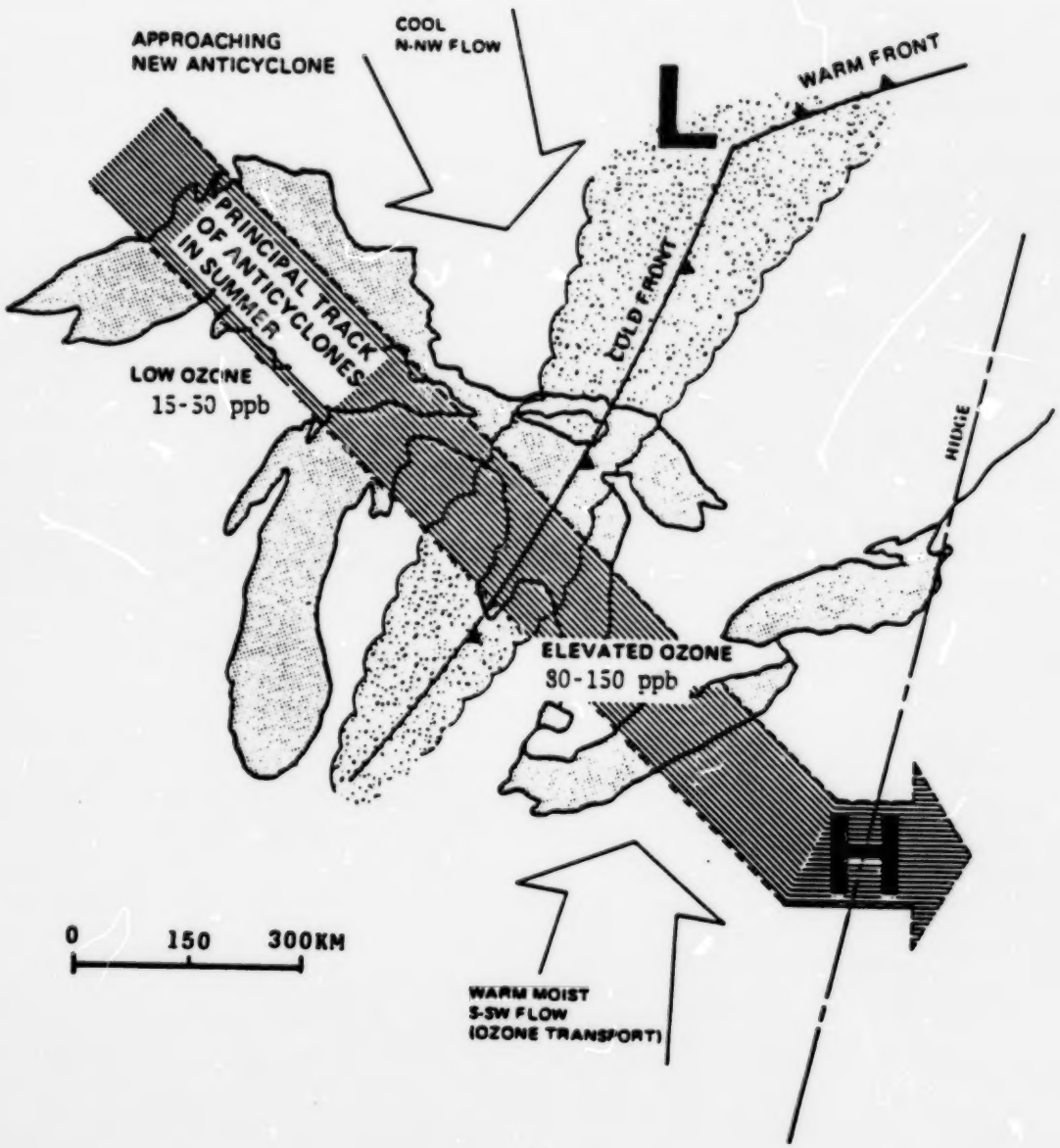

Fig. 1. GENERALIZED SYNOPTIC WEATHER PATTERN OVER SOUTHERN ONTARIO WITH ASSOCIATED TYPICAL OZONE CONCENTRATIONS.

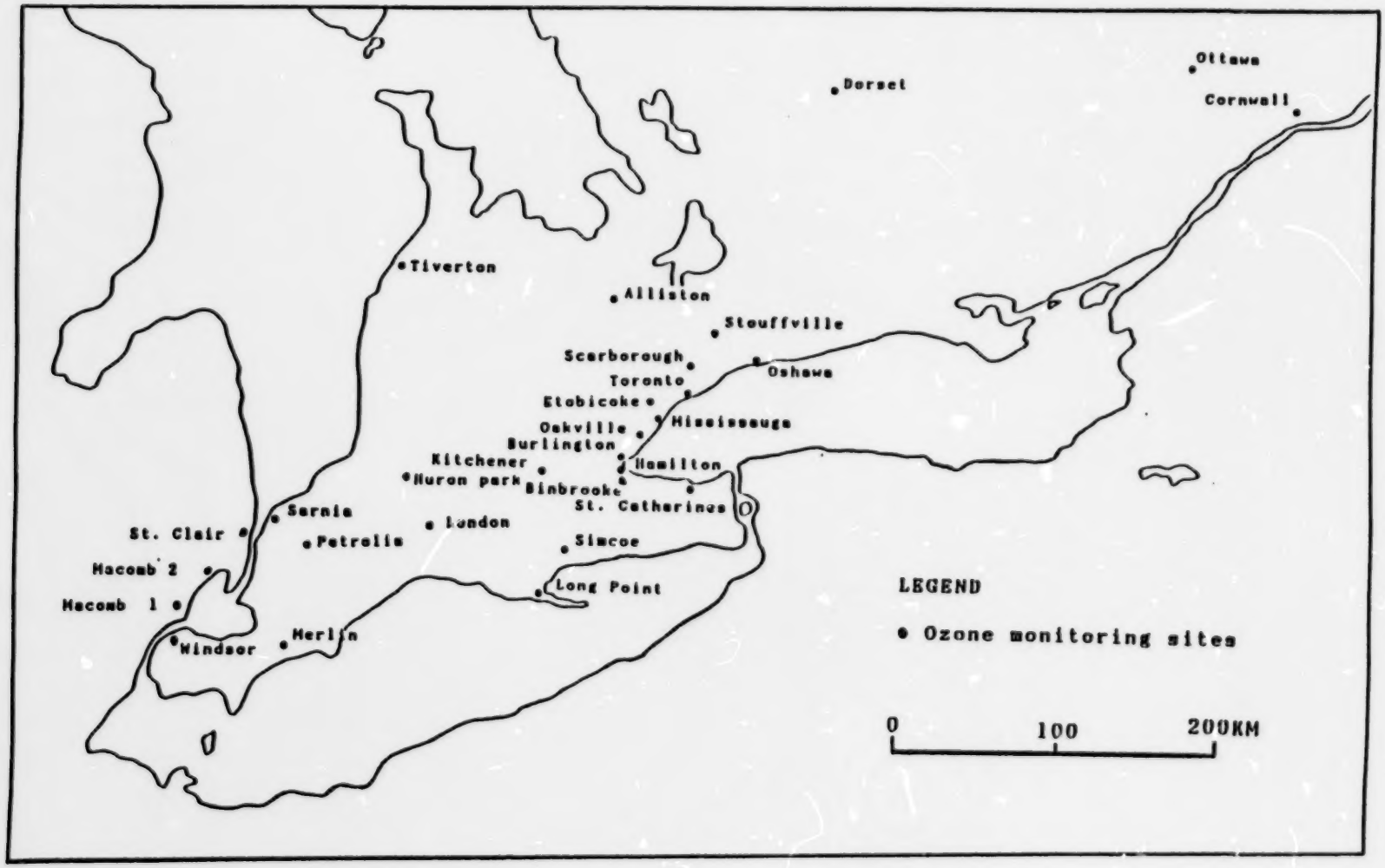

Fig. 2. LOCATION OF OZONE MONITORING SITES IN SOUTHERN ONTARIO.

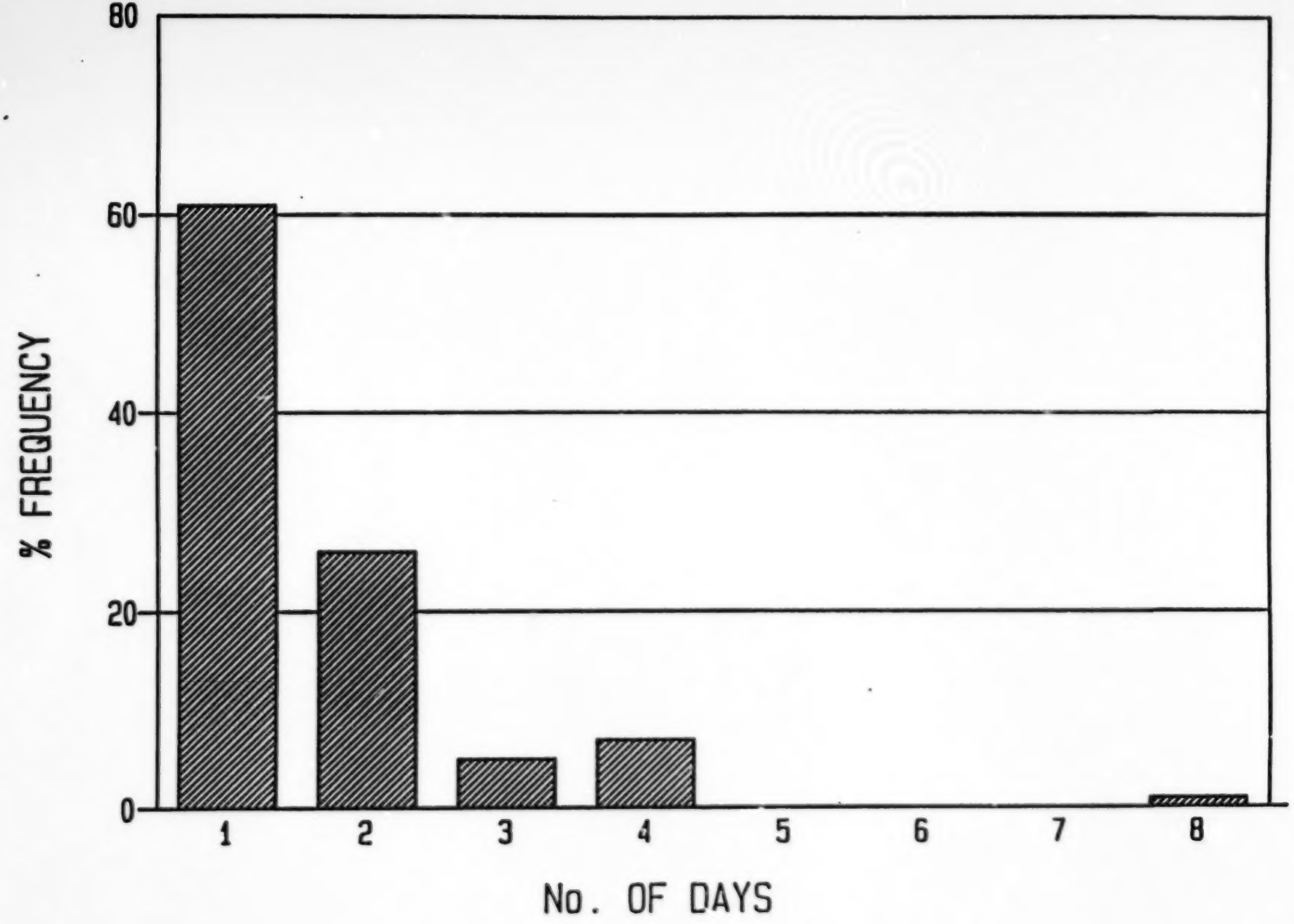

Fig. 3 FREQUENCY OF "EPISODE" DURATION OVER SOUTHERN ONTARIO DURING 1979-1985.

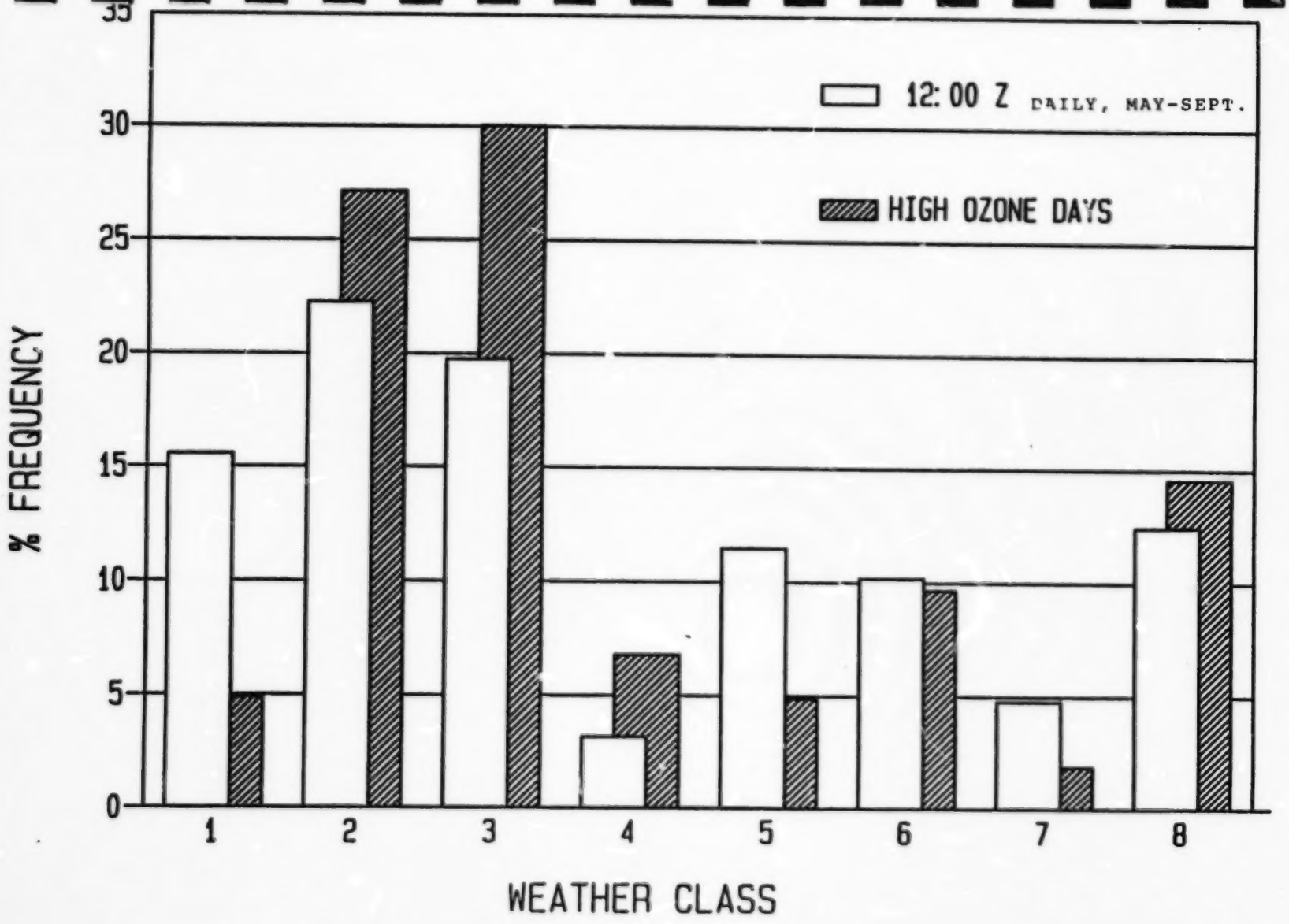

Fig. 4 FREQUENCIES OF WEATHER CLASSES ON OZONE "EPISODE DAYS" AND DAILY DURING MAY - SEPT., 1979 - 1985.

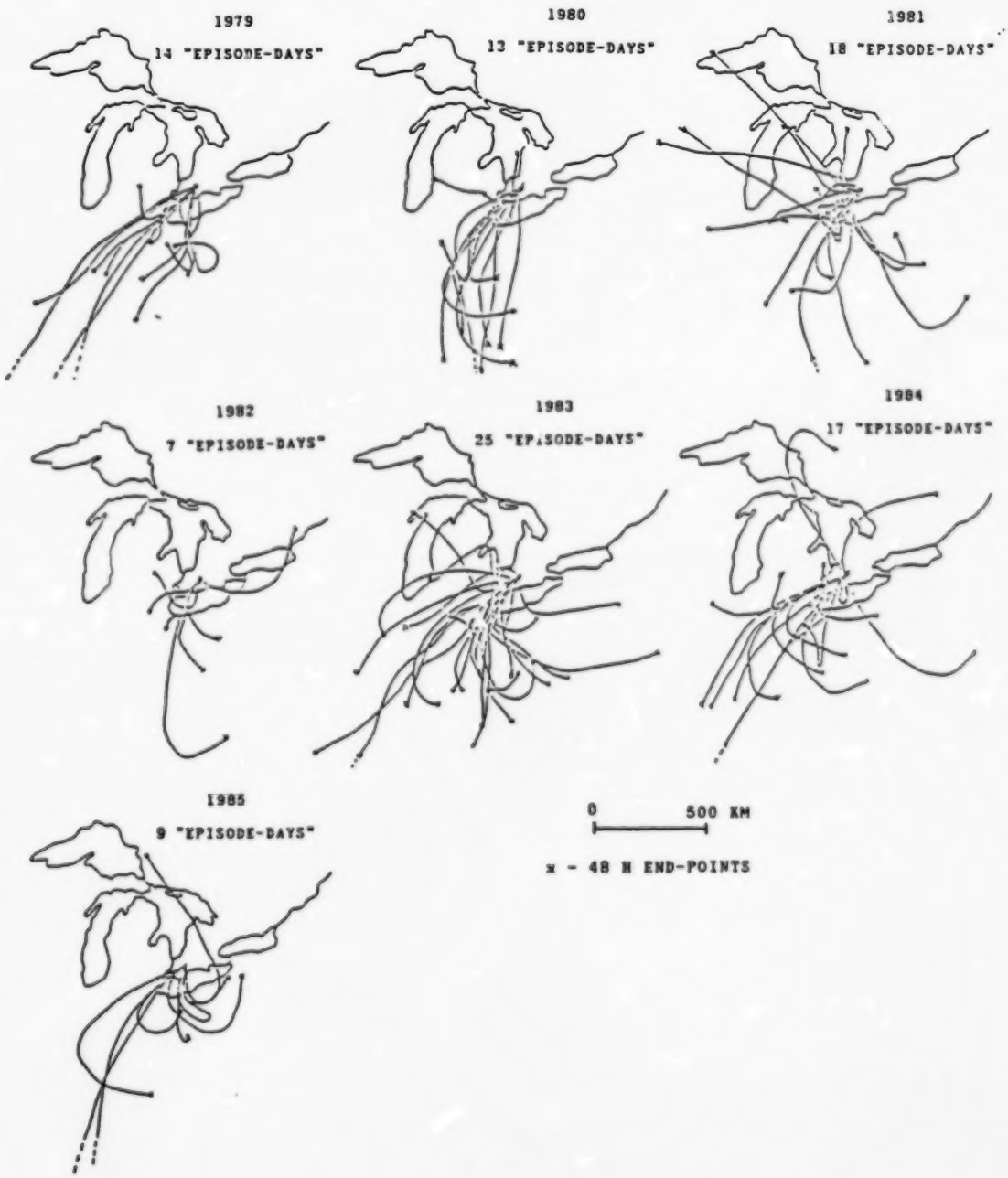

Fig. 5 48-HOUR BACK TRAJECTORIES OF AIR PARCELS ON "EPISODE DAYS" IN SOUTHERN ONTARIO.

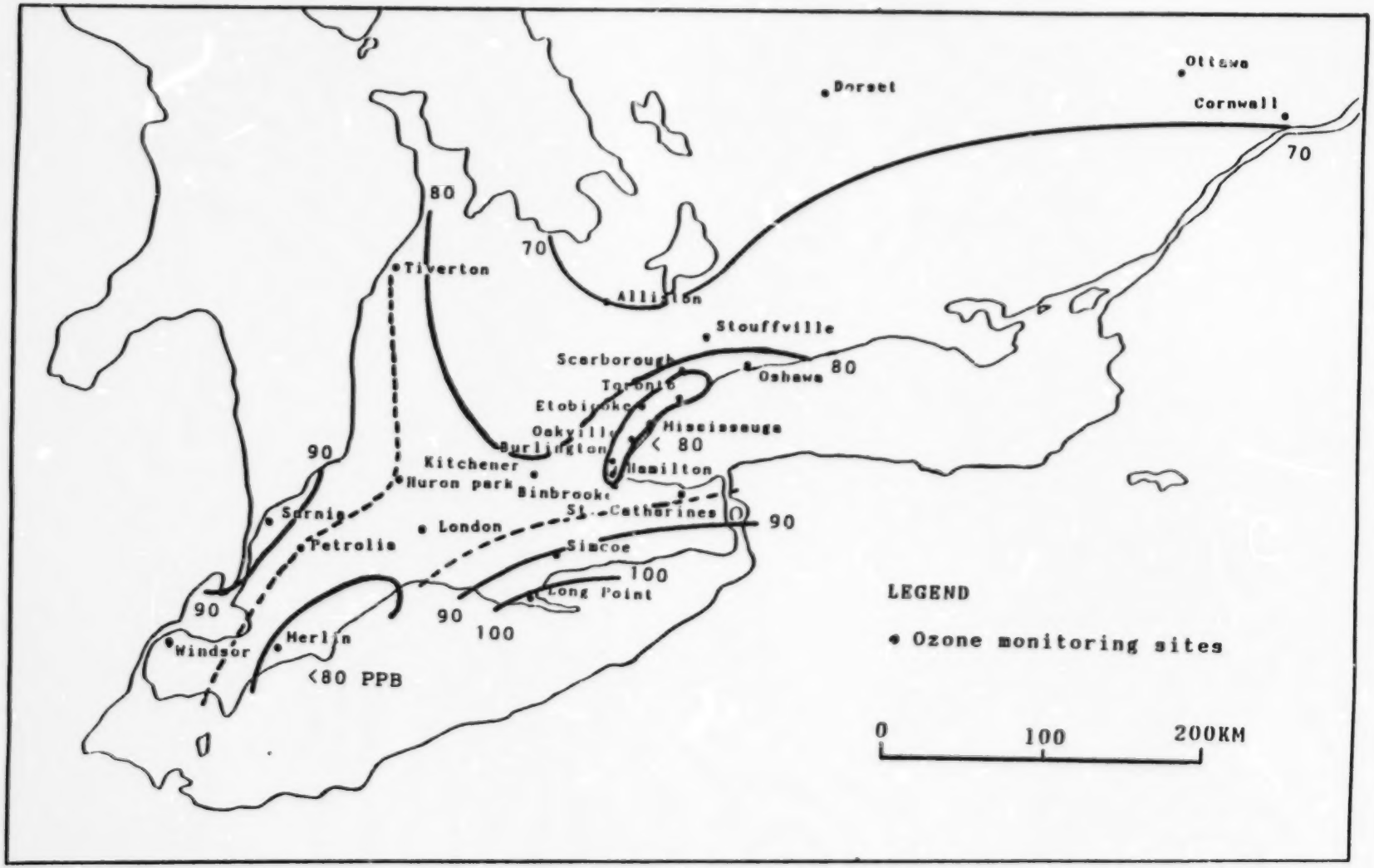

Fig. 6 AVERAGE HOURLY 03 MAXIMA FOR 103 "EPISODE DAYS" DURING THE PERIOD 1979-1985.

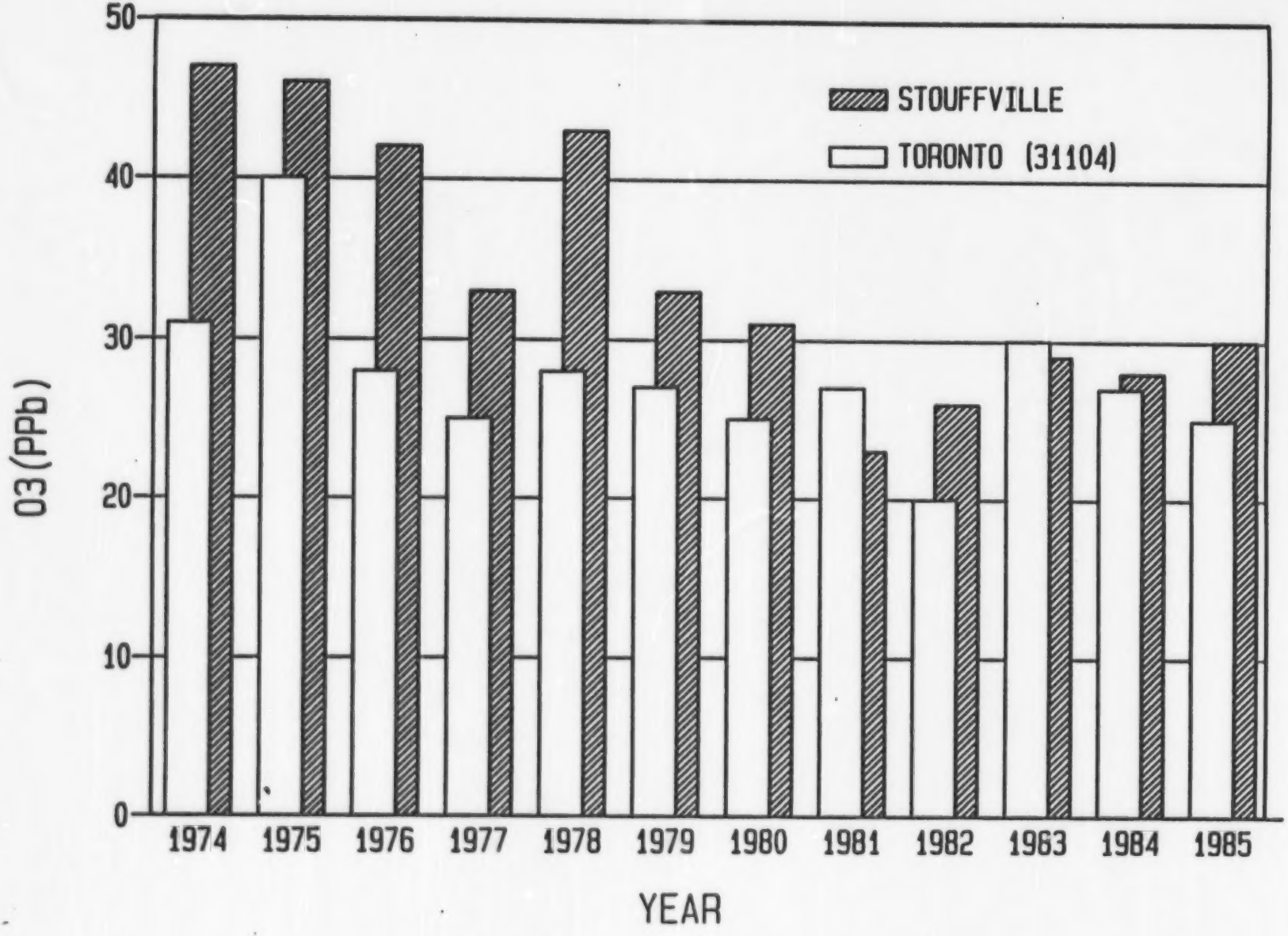

Fig. 7 COMPARISON OF MEAN HOURLY OZONE LEVELS FOR TORONTO AND STOUFFVILLE FOR THE SUMMER MONTHS (JUNE - AUGUST).

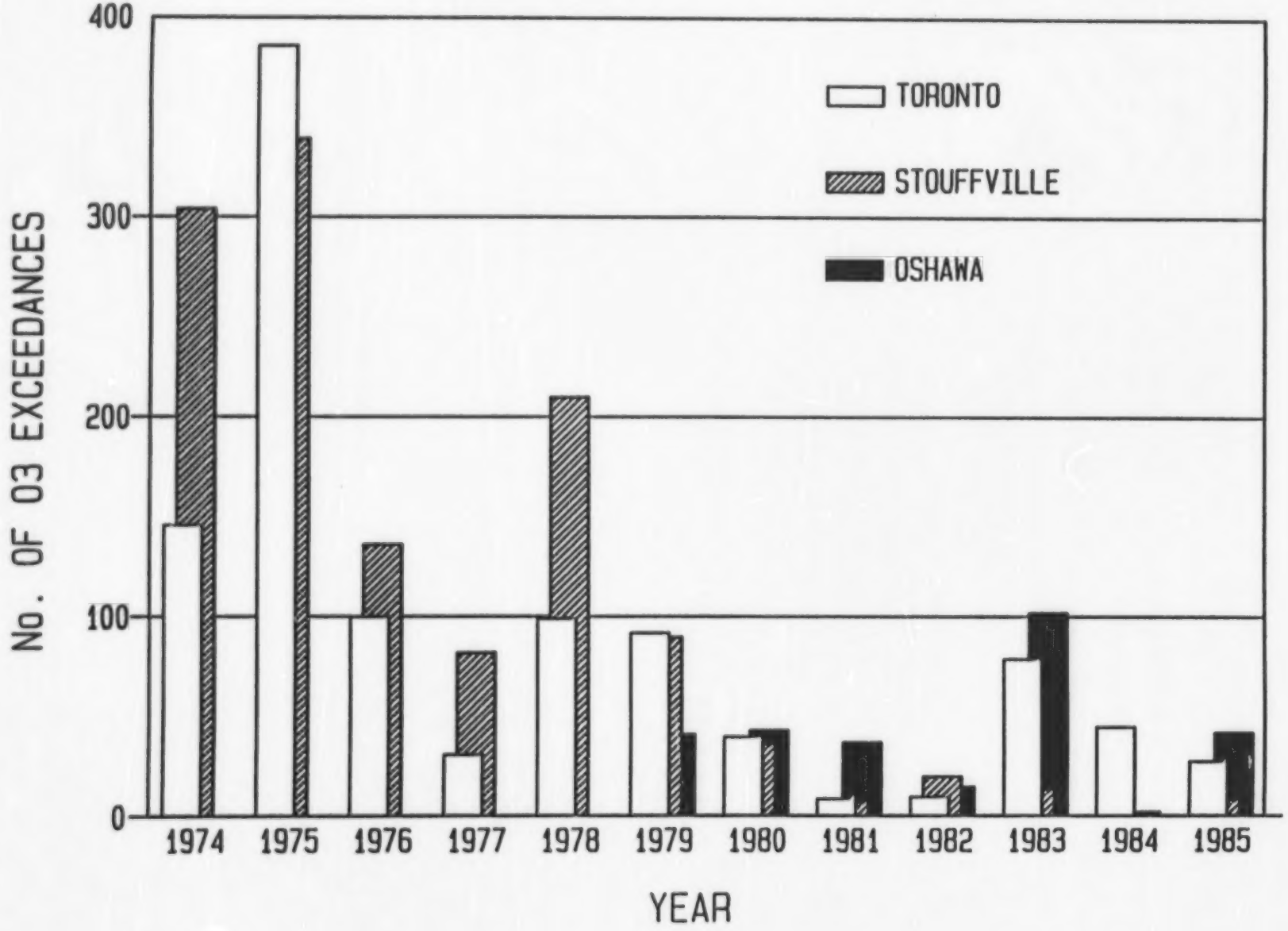

Fig. 8 TREND OF OZONE EXCEEDANCES (> 80 ppb) at TORONTO, STOUFFVILLE, AND OSHAWA.

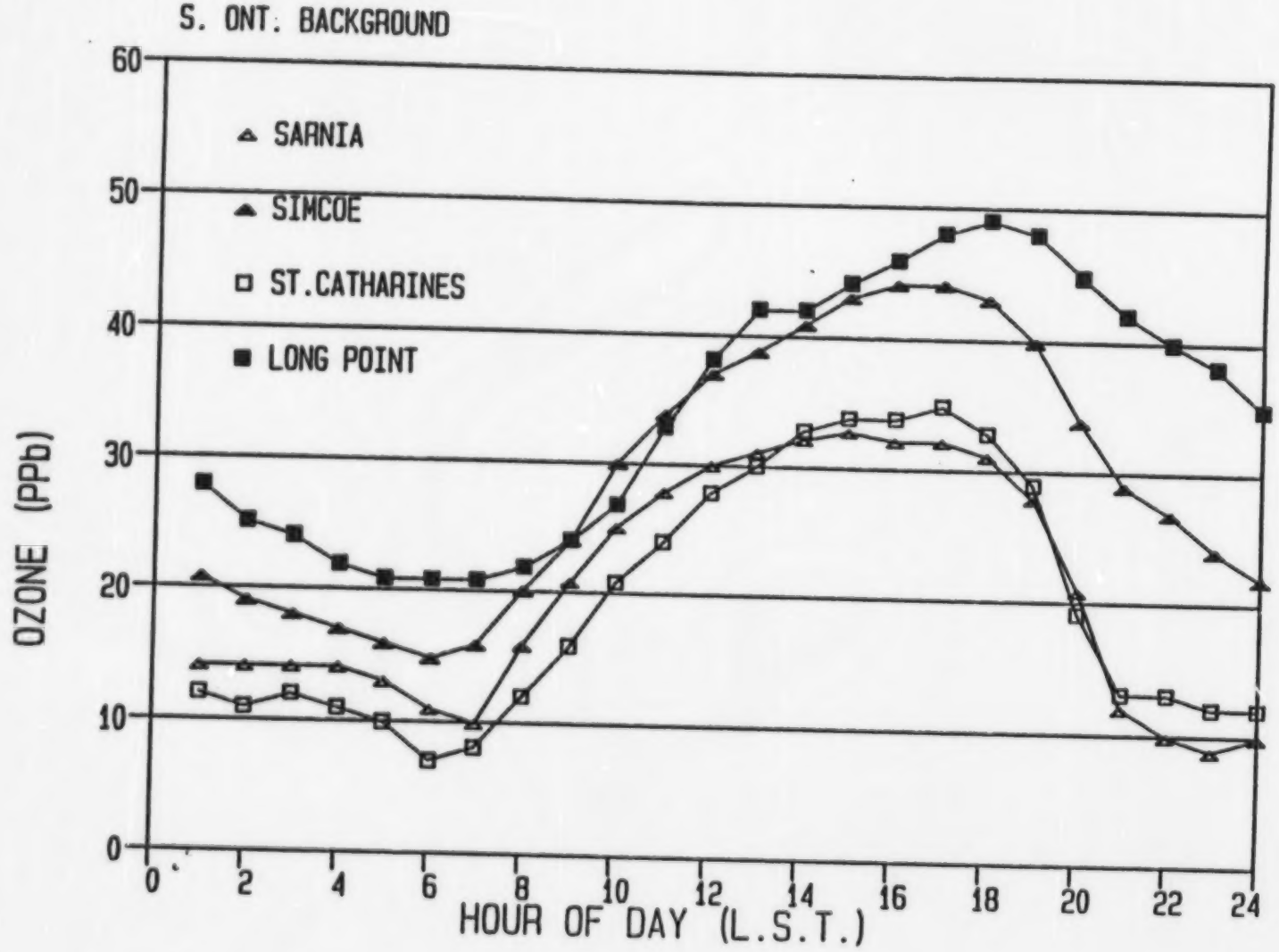

Fig. 9 DIURNAL VARIATION OF "BACKGROUND" OZONE LEVELS IN SOUTHERN ONTARIO.

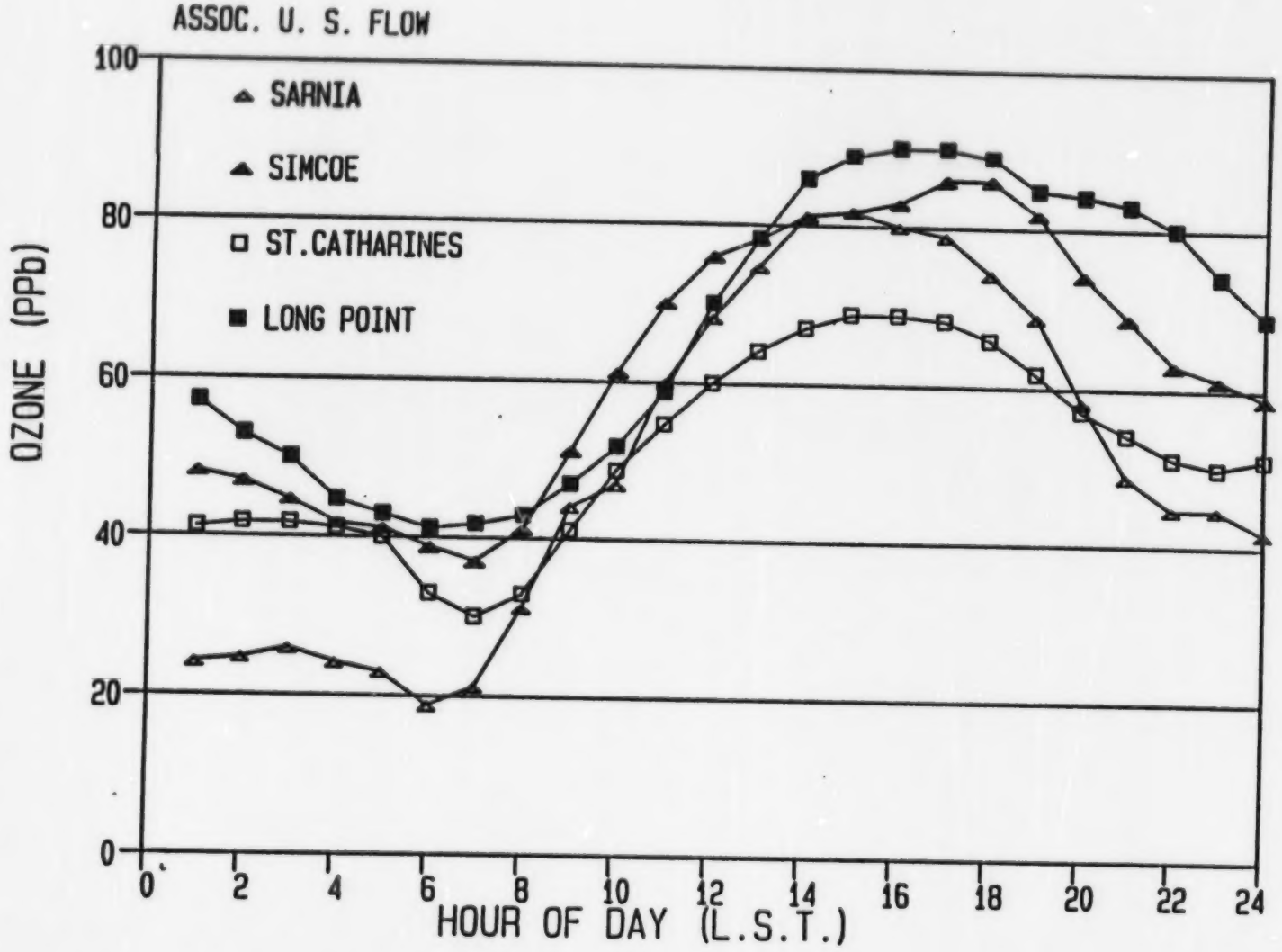

Fig. 10 DIURNAL VARIATION OF OZONE LEVELS IN SOUTHERN ONTARIO ASSOCIATED WITH AIR FLOWS FROM THE U.S.

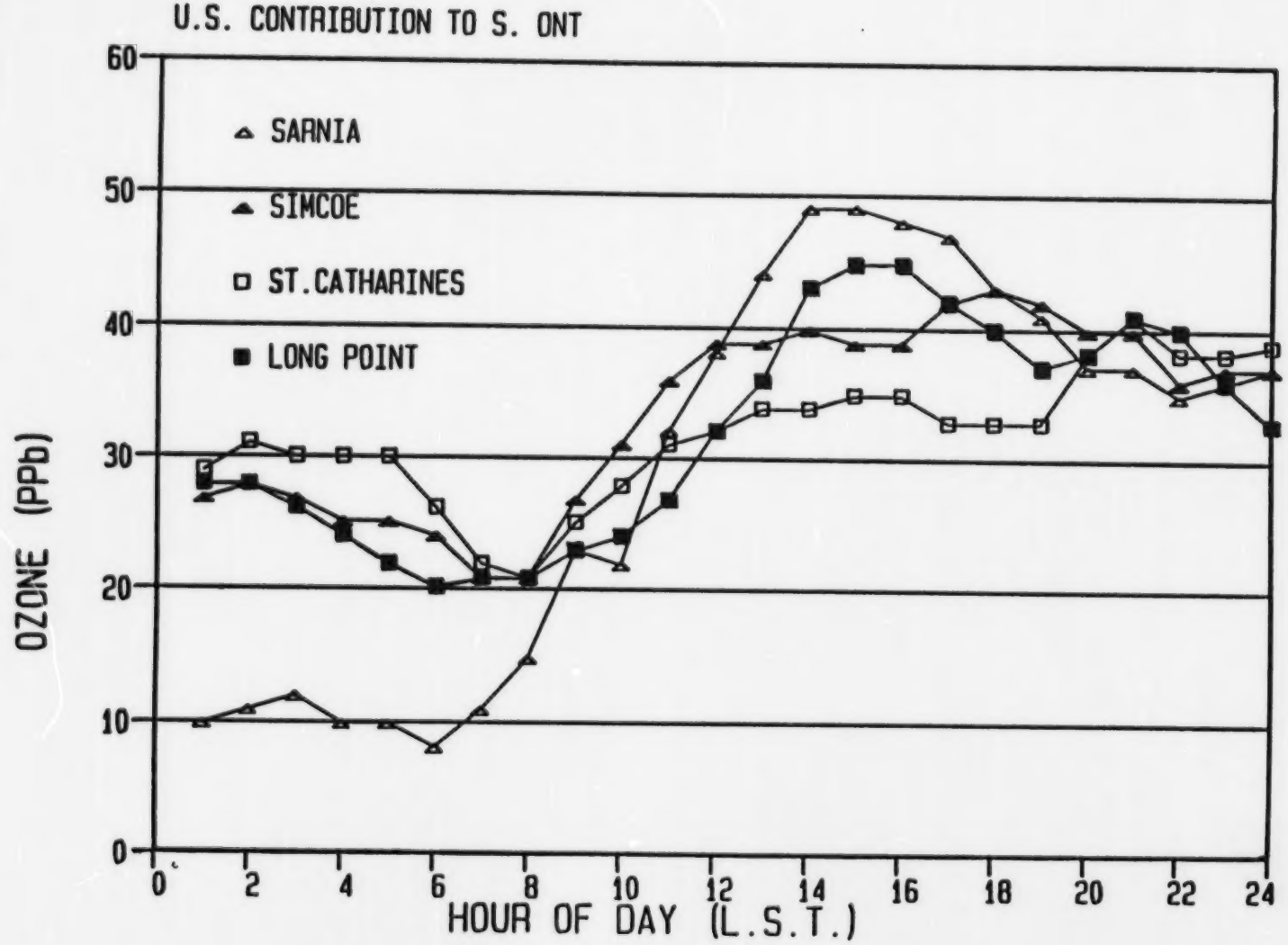

Fig. 11 DIURNAL VARIATION OF ESTIMATED U.S. CONTRIBUTED OZONE TO SOUTHERN ONTARIO.